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Speed of Sound in Four Elastomers

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13. ABSTRACT

Elastomer compounds are widely used in the construction of underwater electroacoustic transducers. The speed of sound in these compounds, and other physical properties as well, can differ over a wide range, depending not only on the ingredients in the compounds but also on curing time, curing temperature, and other factors.

Measurements made at 5-7 kHz on four elastomer compounds provide sound speed values as a function of both temperature (5-40°C) and hydrostatic pressure (atm to 10 000 psi).

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Abstract

Elastomer compounds are widely used in the construction of underwater electroacoustic transducers. The speed of sound in these compounds, and other physical properties as well, can differ over a wide range, depending not only on the ingredients in the compounds but also on curing time, curing temperature, and other factors.

Measurements made at 5-7 kHz on four elastomer compounds provide sound speed values as a function of both temperature (5-40°C) and hydrostatic pressure (atm to 10 000 psi).

Problem Status

This is an interim report on one phase of the problem; work is continuing on this and other phases.

Problem Authorization

NRL Problem S02-32

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SPEED OF SOUND IN FOUR ELASTOMERS

Introduction

An elastomer included in the construction of a hydrophone or sonar transducer often affects the acoustic performance of the device. For this reason, a knowledge of the physical properties of elastomers is very important to a designer. Sound speed, for example, usually is different in each elastomer compound and is, furthermore, a function of temperature and hydrostatic pressure.

Many measurements of sound speed reported in the past were made in the frequency range 100-400 kHz. Data presented here for the range 5-7 kHz should provide better values for use in designing low-frequency transducers.

The elastomers selected for the sound-speed measurements are compounds used at the USRD in transducer construction. Two of them are butyl compositions having low water permeability. Another is a natural rubber compound commercially available from the B. F. Goodrich Company. The fourth is a Neoprene W compound reported to have high elasticity and low internal losses at audio frequencies.

Elastomer Compounds

The speed of sound in each elastomer is affected by the basic ingredients in the compound, the curing time, and the curing temperature. Many other factors such as the age of the ingredients, mastication and mixing time, order of adding ingredients, and how the raw materials are stored, also can have an effect.

Three of the materials were compounded by Smithers Laboratories, Inc. of Akron, Ohio. The fourth was obtained from the B. F. Goodrich Company. In each instance, the uncured compound was sheeted off by the supplier in thicknesses of 0.64 to 1.3 cm (¼ to ½ in). The uncured stock was stored under refrigeration until required for molding and vulcanization.

The compound ingredients for three of the elastomers are known:

Butyl Rubber Compound NASL-H862A

Ingredient	*phr*
Chlorobutyl HT-1066	100
Sterling V black	50
Litharge	10
Stearic acid	1
AC polyethylene 617A	3
DPG	2
Maglite M	1
Zinc oxide	5
NA-22	1.5

Cure 1 hour at 310°F. Characteristics are as follows:

Tensile strength	1625 psi
Elongation, ultimate	375%
Modulus at 300%	1500 psi
Hardness (Shore A)	55-60
Water permeability, 20 °C	8×10^{-10} gm water/cm^2/cm/hr/mmHg

Butyl Rubber Compound B252

Ingredient	*phr*
Butyl 150	100
Pelletex (SRF)	50
Zinc oxide	5
Red lead (Pb_3O_4)	10
Circo light process oil	5
Dibenzo GMF	3
AA-1177-20	6

Cure 1 hour at 307°F. The volume resistivity of this compound may be too low for some applications. Characteristics are as follows:

Tensile strength	1310 psi
Elongation, ultimate	575%
Modulus at 300%	790 psi
Hardness (Shore A)	50-60
Water permeability, 20 °C	12×10^{-10} gm water/cm^2/cm/hr/mmHg

Neoprene Compound G6470

Ingredient	*phr*
Neoprene W	75
Neoprene WHV	25
Zinc oxide	5
Magnesium oxide	4
Stearic acid	0.5
Antiox 2246	2

Ingredient	*phr*
Dioctyl sebacate	10
Iceberg clay	40
Titanox (TiO_2)	15
NA-22	0.5
Cyanamid blue	0.15

The list of ingredients for the B. F. Goodrich black rho-c compound 35001 is not known. It is a natural rubber compound, however, and must be protected from prolonged exposure to sunlight and mineral oil. Its characteristics are as follows:

Tensile strength	4500 psi
Modulus at 300%	1000 psi
Hardness (Shore A)	52
Water permeability 40 °C	308×10^{-10} gm water/cm^2/cm/hr/mmHg

Measurement Technique

The measurements were made in the USRD 5.08-cm Acoustic Impedance Tube Facility [1], which permits the frequency to be varied from 3 to 9 kHz, the hydrostatic pressure from 100 to 10,000 psi, and the temperature from 5 to 40°C (temperature control was added recently and is not described in the paper by Sabin [1]).

The samples were between 14 and 15 cm long. They were attached to the reflector with a small screw partially imbedded in one end of the sample (Fig. 1). Each sample was installed in the tube through a water-filled pan that fits over the open end of the tube, so as to avoid trapping air bubbles with the sample. The density was determined by standard techniques.

Results

The curves of sound speed as a function of hydrostatic pressure (Figs. 2 through 5) were plotted from an average value of sound speed determined by measurements at 5, 6, and 7 kHz, which appears to be the frequency range of greatest accuracy for the Impedance Tube. The sound speed in water in the tube is 2.3% less than that in a free field; hence, a first-order correction of +2.3% was applied to the data before plotting. The curves for sea water are shown for reference purposes in Fig. 6.

The curves display an expected direct relationship between sound speed and hydrostatic pressure and a generally inverse relationship between sound speed and temperature. The magnitude of the sound speed, however, is lower than might be expected from comparison with data for higher frequencies, but recall that the plane-wave compressional speed in a solid is $[(K + 4\mu/3)/\rho]^{1/2}$, where K is the bulk modulus, μ is the shear modulus, and ρ is the density [2]. The value of K usually is assumed to be independent of frequency for rubber, but μ is not. For natural,

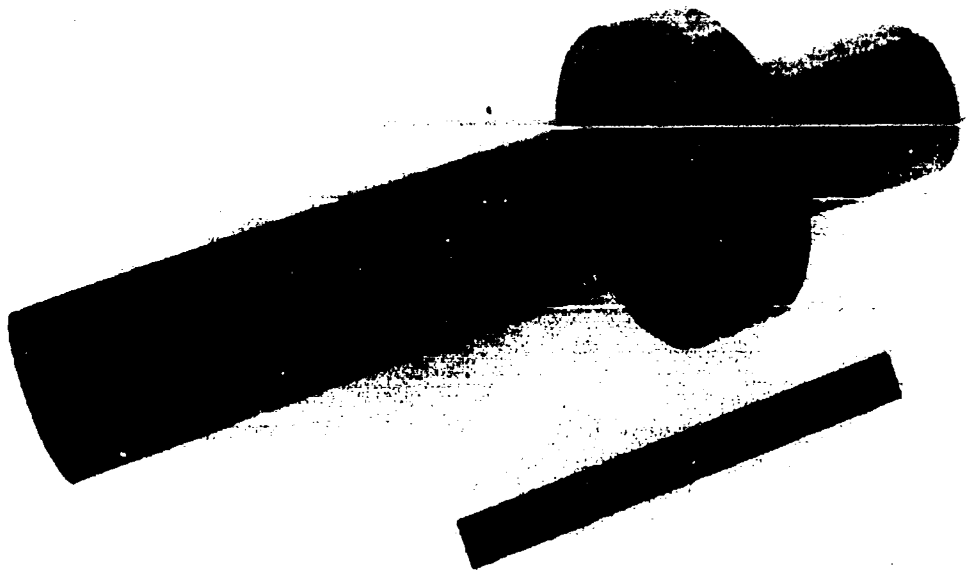

Fig. 1. An elastomer sample attached to the reflector.

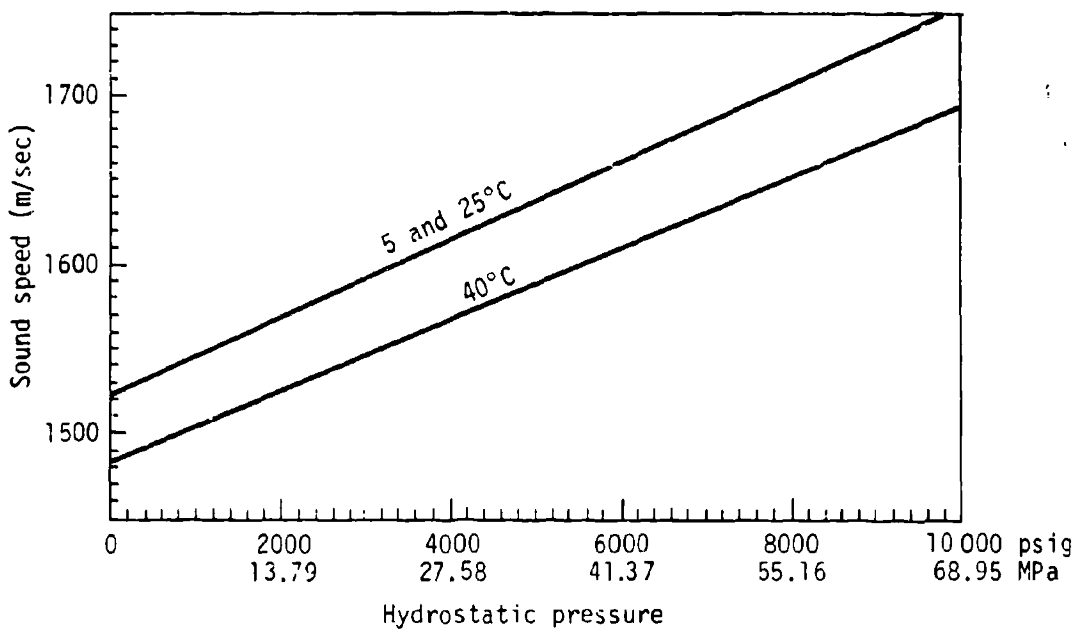

Fig. 2. Sound speed in natural rubber, black, 35001 (specific gravity, 1.10) as a function of hydrostatic pressure.

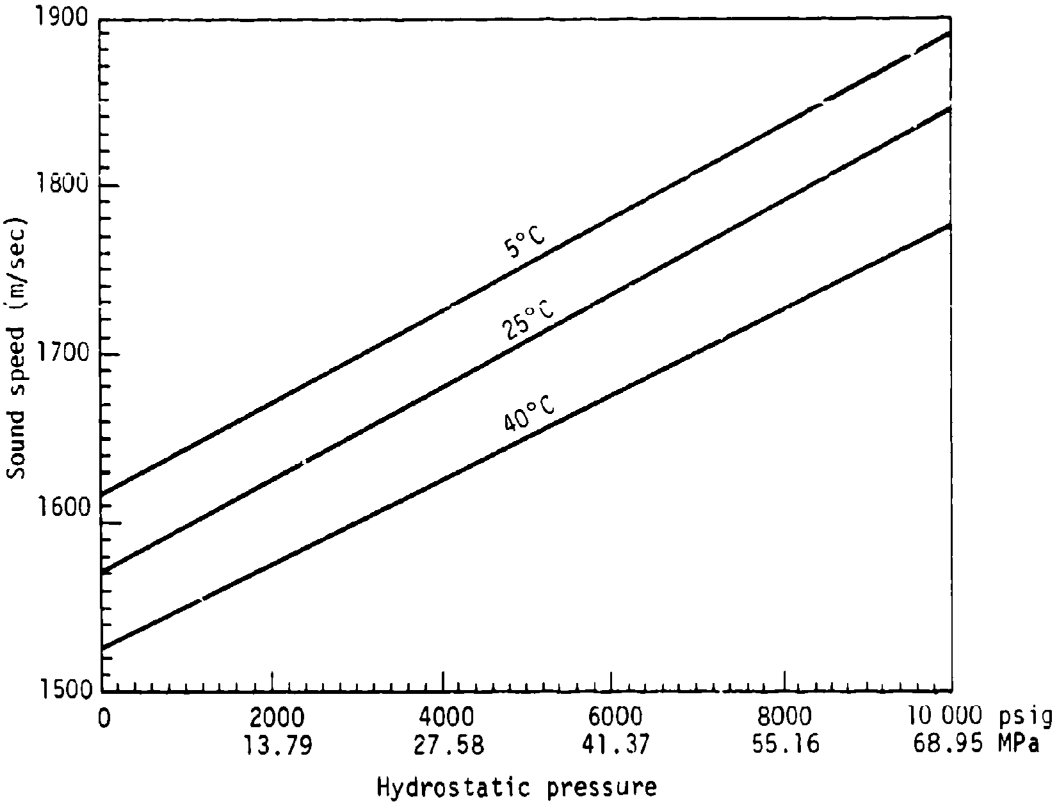

Fig. 3. Sound speed in butyl rubber compound NASL-H862A (specific gravity, 1.20) as a function of hydrostatic pressure.

butyl, and neoprene rubbers, the shear modulus increases with frequency above the audio range [3,4]. They appear to behave like a Kelvin body in that the shear modulus is low at low frequencies and passes through a transition to a higher value at high frequencies. Consequently, the sound speed increases also. Curves for sound speed as a function of temperature are shown in Fig. 7 for atmospheric pressure.

The attenuation constants measured were all small. The largest, for the H862A sample, was less than 5 dB/m at 5 kHz and 5°C; this value decreased to 2 dB/m at 40°C. The value for the B252 sample was slightly less than this. For the other two samples, the attenuation constants were less than 2 dB/m at all temperatures, which is less than the measurement error.

The measurement error is estimated as ±2% for sound speed and ±2 dB/m for the attenuation constants.

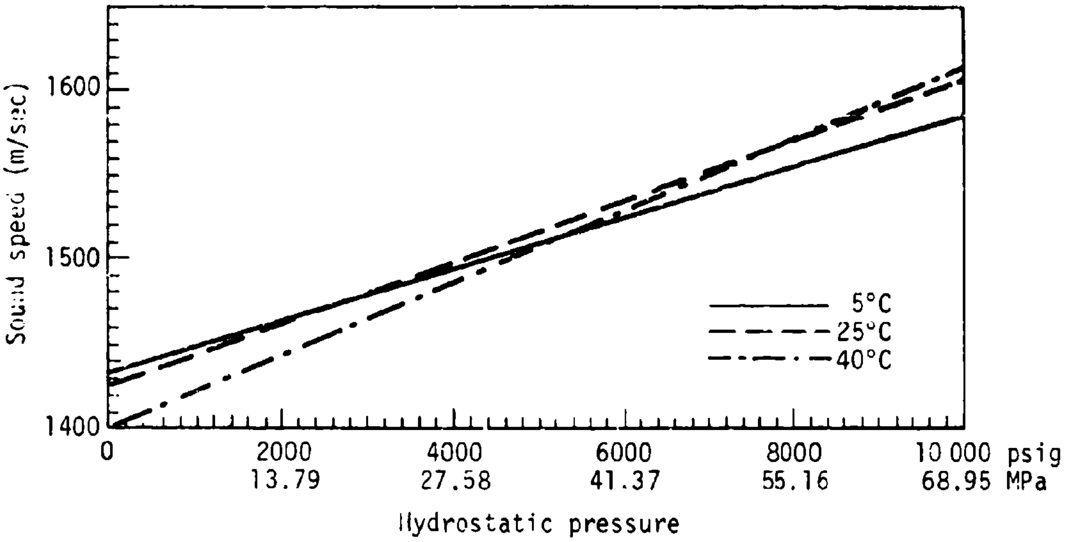

Fig. 4. Sound speed in neoprene compound G6470 (specific gravity, 1.54) as a function of hydrostatic pressure.

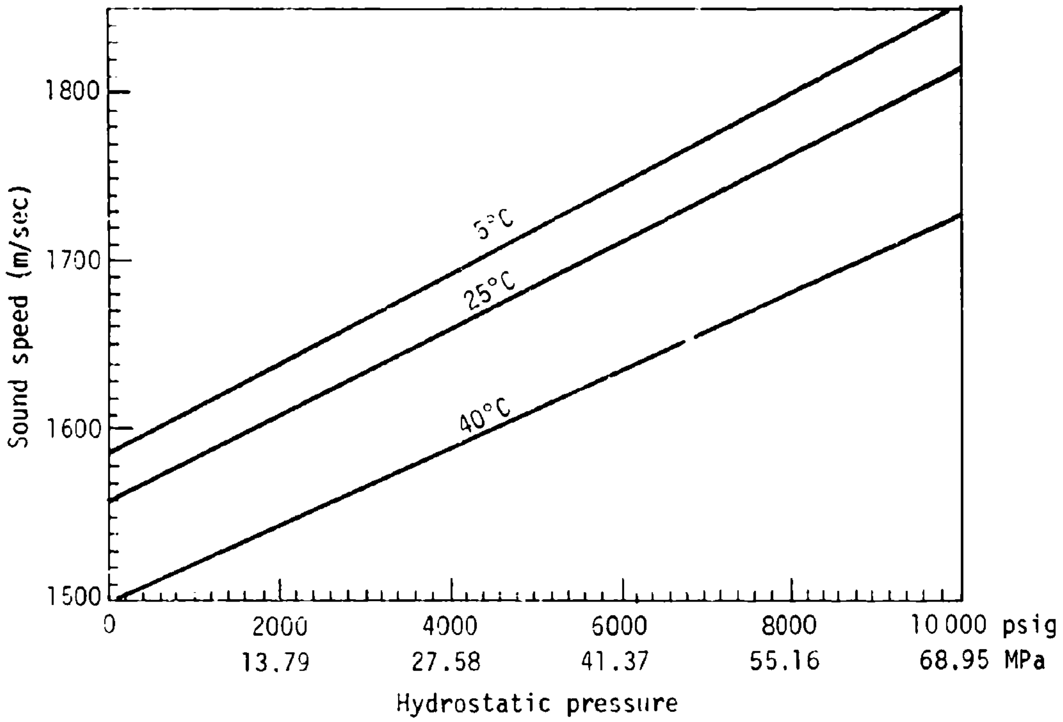

Fig. 5. Sound speed in butyl rubber compound B252 (specific gravity, 1.18) as a function of hydrostatic pressure.

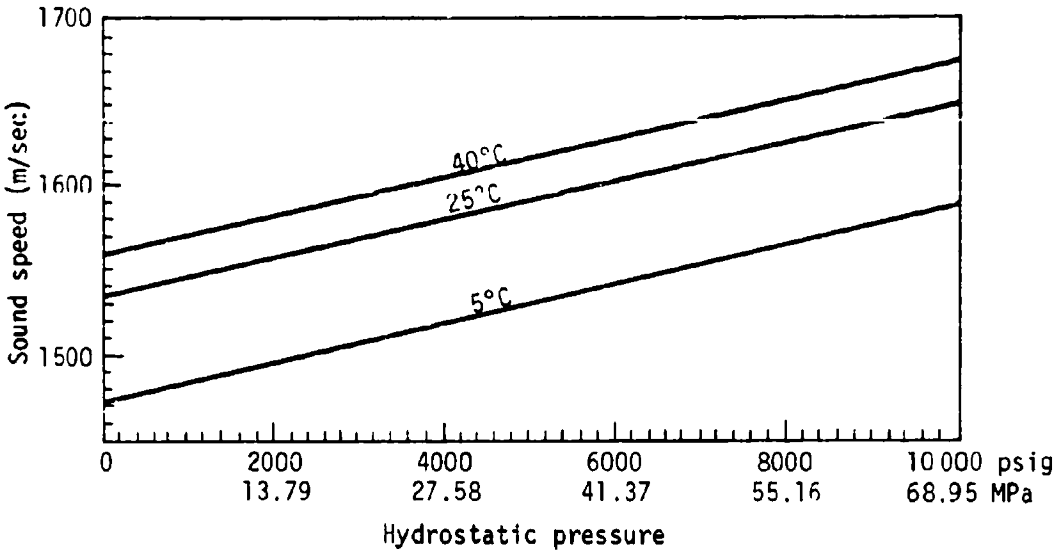

Fig. 6. Sound speed in sea water (salinity, 35 o/oo) as a function of hydrostatic pressure.

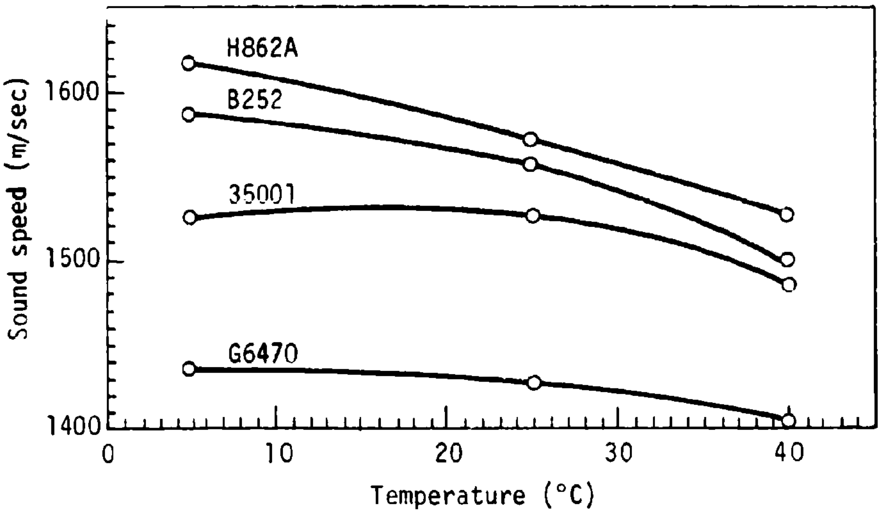

Fig. 7. Sound speed in the four elastomers at atmospheric pressure as a function of temperature.

Conclusions

The sound speed can vary widely in each elastomer compound. The changes in sound speed caused by temperature changes are less predictable than those caused by hydrostatic pressure changes. Compounding of a given type of elastomer (butyl compounds with different ingredients, for example) will produce materials with each having its own sound speed-versus-temperature characteristic. Even though the rho-c of the elastomer may match that of water at some combination of temperature and hydrostatic pressure, it will not necessarily do so at all temperatures and pressures.

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